University of Central Florida

Department of Electrical & Computer Engineering
Senior Design 2 – Fall 2019

Project Summary

SmartLeaf

Indoor Greenhouse System

Group 12
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Introduction

Most people can appreciate the aesthetic and air-purifying qualities that house plants have to offer – not to mention the potential savings and health benefits of growing fruits and vegetables – but generally lack the 'green thumb' needed to keep them alive and happy. With greater monitoring and control of the plant's environment, indoor gardening can become more feasible for the typical household. The SmartLeaf Indoor Greenhouse System offers a user-friendly experience and introduction to the benefits of indoor gardening.

The driving motivation for this project was to address the rise of "food deserts". Defined by the USDA as regions of the country without ready access to healthy and affordable food, it is estimated that 23.5 million Americans live in these regions and lack reliable transportation to affordable grocery stores [1]. Residents of these low-income areas are typically forced to rely on convenience stores with limited produce selection at prices of up to 37% more than their middle-income peers pay [1]. While clever gardening solutions are not enough to singlehandedly combat the root of poverty and inequality, community-based urban gardening programs across the nation have proven their ability to positively impact these food deserts. We believe the SmartLeaf system can do the same – and all the while spark an interest in electronics for the user.

Project Description

The SmartLeaf system is designed to monitor and provide a nurturing environment for fruits and vegetables with small to mid-sized root structures. These plants are provided water, humidity, light, and airflow through the use of sensors, pumps, fans, humidifier, LEDs, etc. The physical layout and configuration of these systems can be seen in Figure 1 and Figure 2 below.

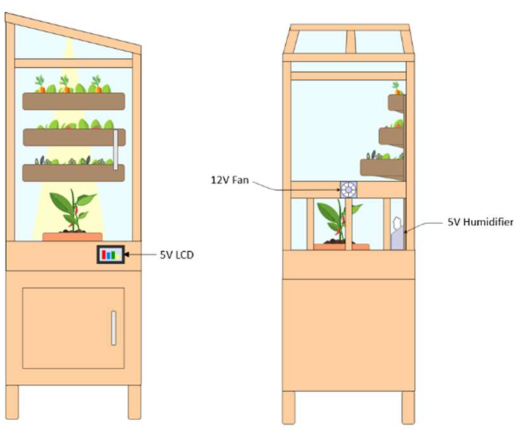

Figure 1 - Front and side view of the SmartLeaf System

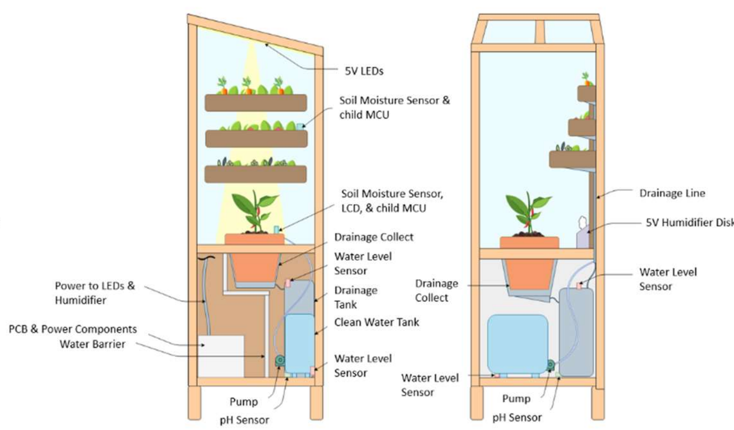

Figure 2- Front and side section view of the SmartLeaf System

The control mechanisms, i.e. the pumps, fans, humidifier, and LEDs are triggered either on a timed schedule, when a sensor parameter indicates a low/high reading, or both. For example, the fans are to be activated by the parent MCU upon receiving humidity readings above 60% from the hygrometer; but, they are also triggered at certain time intervals to provide regular airflow for the general health of the plants. The pumps activate autonomously when the soil moisture sensor in a particular plant bed reads low – strictly on an interrupt from that sensor – while the LEDs operate exclusively on timers. The specifications of the control routines and general system parameters are defined in Table 1.

The operation of the complete system is largely dependent on Bluetooth communication between the parent MCU located in the unit's base enclosure, and the child MCUs in the upper greenhouse portion. This allows for fewer wires between the base and the Plexiglas enclosure, aiding with waterproofing and improving the general appearance of the unit. The responsibility of the child MCUs is to poll the soil moisture sensors and the temperature/humidity sensors and send that information to the parent MCU. From there, the parent can trigger the various control systems and display environmental data on a local GUI and on a web application through a WiFi module. In addition to displaying current environmental data on the two interfaces, the parent also communicates data from the tanks' water level and pH sensors, notifying the user of any actions to take – i.e., to empty the runoff water tank as it is at capacity, the water supply tank is empty, the soil is too acidic/basic for optimum growth conditions, etc. The flowchart shown in figure 3 displays the general operation of the SmartLeaf Indoor Greenhouse System.

Table 1 - SmartLeaf specifications

Parameter	Specification
Height	< 6ft
Weight	< 50lbs
Max. Power Consumption	7.1W
Bluetooth Range	10m
Humidity Range	50-60%
LED Growlight Sequence Time	6-8hrs
Hygrometer Polling Rate	1 measurement per minute
Soil Moisture Sensor Polling Rate	1 measurement every 6 hrs

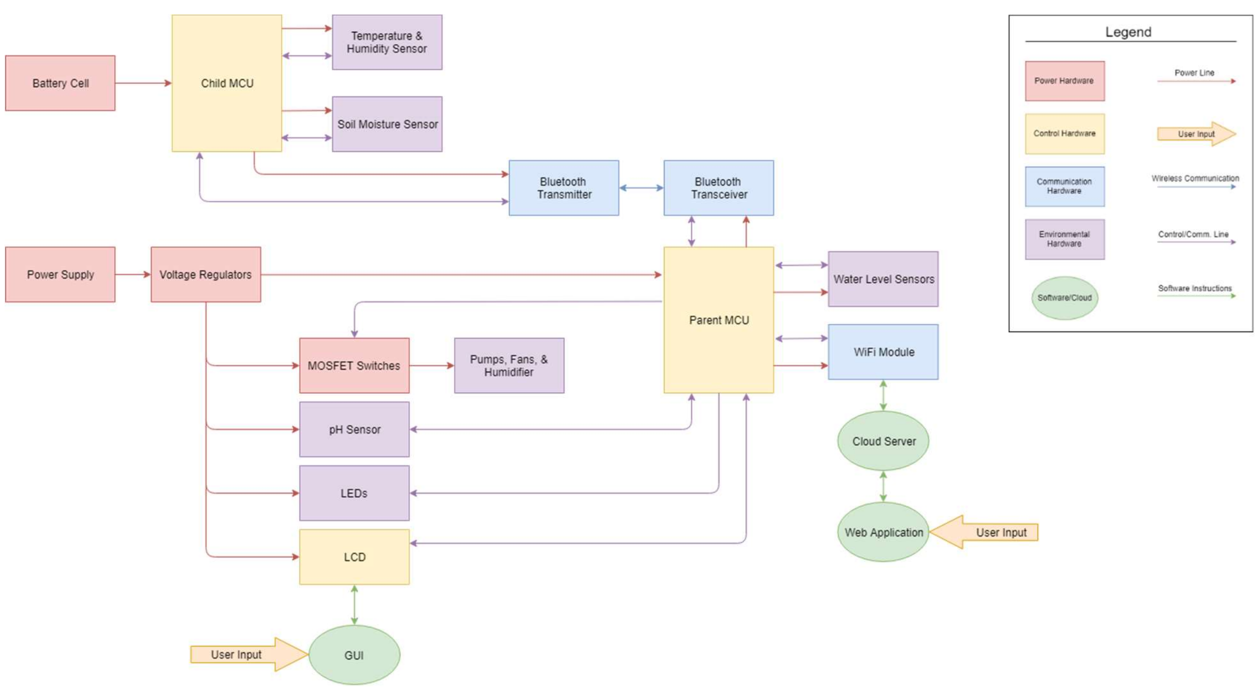

Figure 1 - Flowchart for the SmartLeaf System

Hardware Selection

With the intended use and functionality of the system determined, main hardware components – power supply, fans, pumps, LEDs, humidifier, LCD touchscreen, and associated sensors – could be selected and designed around. The determining factors considered were cost, size, power consumption, and compatibility with Texas Instruments' MSP line of microcontrollers. General functionality in a greenhouse environment was also considered for the components, specifically in the selection of a water resistant power supply and fans that could provide maximum airflow to the plants (high CFM). Table 2 denotes the components selected for this project.

Table 2 – Main Hardware Selections for the SmartLeaf System

Device	Description	Manufacturer	Vin	Operating Current	Price
PH0-14	pH Sensor	GAOHOU	5V	5-10mA	$37.99
10100012	Soil Moisture Sensor	Smart Prototyping	3.3-5V	<20mA	$2.99
DHT22	Temperature & Humidity Sensor	Adafruit	3-5V	2.5mA	$9.95
SEN-2609	High Sensitivity Water Sensor	Emartee	3.3-5V	<20mA	$4.99
CFM-6015-13-22	Fan	CUI	12V	220mA	$8.74
11434	Humidifier	IC Station	5V	400mA	$5.99
AD20P-1230C	Water Pump	Ledgle	12V	300mA	$8.99
WS2812B	LEDs	Chinly	5V	60mA max per LED	$31.85
B07KPD4DHD	LCD Touchscreen	Wal Front	5V	90mA	$16.59
12V120W	12V/120W IP67 Rated Power Supply	Idealy	120AC	10A max output	$31.99

Power Design

The selection and design of the power components for this project depended entirely on the devices requiring power within the system. Selecting the main power supply transforming the 120V/60Hz AC from mains to DC power for the SmartLeaf system was simple; supplies of these type are widely manufactured and available through multiple retailers at reasonable prices. An IP-67 rated, 12V/10A supply from Idealy was selected for general safety and to meet the overall power demands of the system. The individual power rails were designed to supply the various voltage and current needs to the system, while also providing isolation to the individual components in the hopes of preventing additional failures in any single component were to fail. The use of switching regulators was decided upon early in the design process to curb excessive heat loss and maintain an efficient system. Texas Instruments' Webench Power Architect was utilized as a basis of design for the power rails and greatly aided in selecting the various regulators; other considerations for the component selection of this system were price, footprint, availability, and overall system efficiency. For the child PCBs, a local power supply was needed to limit wires running through the unit. Due to the generally low and infrequent power demands of this device, a 4.2V lithium ion battery and simple LDO regulator were selected to provide a steady 3.3V to the board. In Table 3 below, the regulator selections for all loads in the project are outlined.

Table 3 - Regulator Selections for the SmartLeaf System

Load	Required Voltage	Demand Current	Regulator	Manufacturer	Description	Efficiency	Total Price
LEDs	5V	12A	TPS40305	TI	Switcher: Synchronous Buck Controller	91.7%	$2.99
Pumps	12V	2A	TPS55330	TI	Switcher: X version, 1.6MHz, 22V Internal FET	95.9%	$2.52
Fans	12V	0.44A	LMR62014X	TI	Switcher: Wide Input Range Boost DC/DC Converter	95.6%	$0.82
Humidifier	5V	0.5A	TPS560430Y	TI	Switcher: 4V to 36V 0.6A Synchronous Step-Down Converter	88.5%	$1.27
LCD	5V	0.15A	TPS62175	TI	Switcher: High Light-Load Efficiency Buck Converter	90.6%	$0.96
pH Sensor	5V	0.5A	TPS560430Y	TI	Switcher 4V to 36V 0.6A Synchronous Step-Down Converter	88.5%	$1.27
MSP432	3.3V	0.1A	TPS62177	TI	Switcher: Fixed 3.3Vout, High Light-Load Efficiency Buck Converter	85%	$0.86
MSP430	3.3V	0.1A	HT7333	Holtek	Low Power Consumption LDO	61.8%	$0.95

Control Circuitry Design

While the sensors and LEDs utilized could be controlled from their respective MCUs, other devices such as the pumps, fans, and humidifier lacked the necessary lines for the same method of direct control. Luckily, the aforementioned devices simply required on/off and motor speed control. For this reason, N-channel logic-level MOSFETs (specifically, TI's 40V N-Channel NexFET) were included in the design rather than more complex motor drivers, which generally require multiple GPIO pins. This presented an opportunity to test the controls with readily available components and apply some fundamental principles of transistors within the SmartLeaf system. The gate of this MOSFET is connected to a GPIO pin of the MSP432, the source is grounded, and the drain is connected to the negative terminal of the device to be controlled. When instructed, the MCU can pull the gate high or low to turn the device on or off, respectively. Additionally, this method allows the microcontroller to drive pulse width modulation (PWM) signals on the gate which are utilized in this project to alter motor speed. For the pumps and fans additional circuit protection was included to limit flyback – the sudden voltage spike seen across inductive loads when its supply current is suddenly switched. To curb this effect, a flyback diode with adequate peak repetitive reverse voltage and non-repetitive peak forward surge current was selected. This ended up reducing the flyback spike – previously measured at a peak of 1.6V – to a couple hundred millivolts. Figure 4 shows the design utilized for the inductive loads.

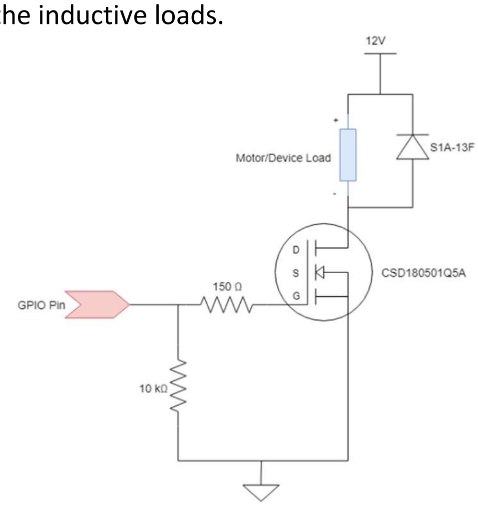

Figure 2 - Flyback reduction circuitry used in the SmartLeaf System

Software Design

Communication is centered around a master ARM microcontroller that is suited with a WiFi module and Bluetooth transceiver. Bluetooth will allow the main MCU to gather data from sensor nodes, forming a star network. Instead of wirelessly connecting all the sensor nodes, we'll push and receive all messages from the main MCU. Once our data is collected, we use PubNub as an MQTT broker to publish the data to a channel that our web application is subscribed to. From there, a JSON string containing our data can be unbundled and displayed for the remote user. Data will be stored in a database for historical reference.

Our web application is built using Losant, an IoT platform for device control and visualization. Users can name each plant and upload a photo to identify it. The current humidity, soil moisture, and temperature sensor readings from the plant are shown in a display guage, along with a table that holds a history of previous readings. Plots show sensor readings over time and compare graphs of data such as Temperature vs Humidity over time. Garden features are also available for display and control on the dashboard. Users may modify LED light colors, update timing frequency of water pumps and fans, and monitor the water tank level. The parent and child UML diagrams can be seen in Figure 3 and Figure 4 below.

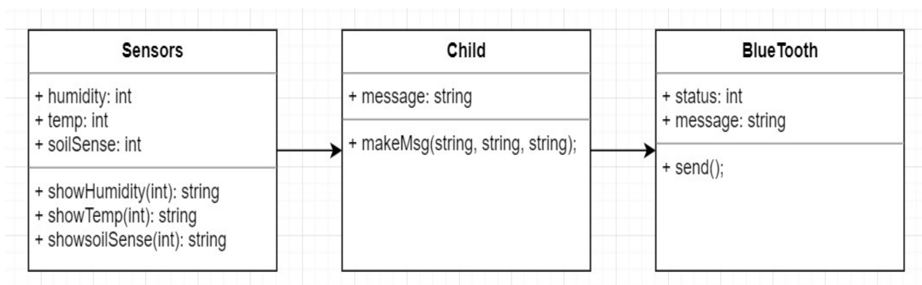

Figure 3 - Child UML diagram

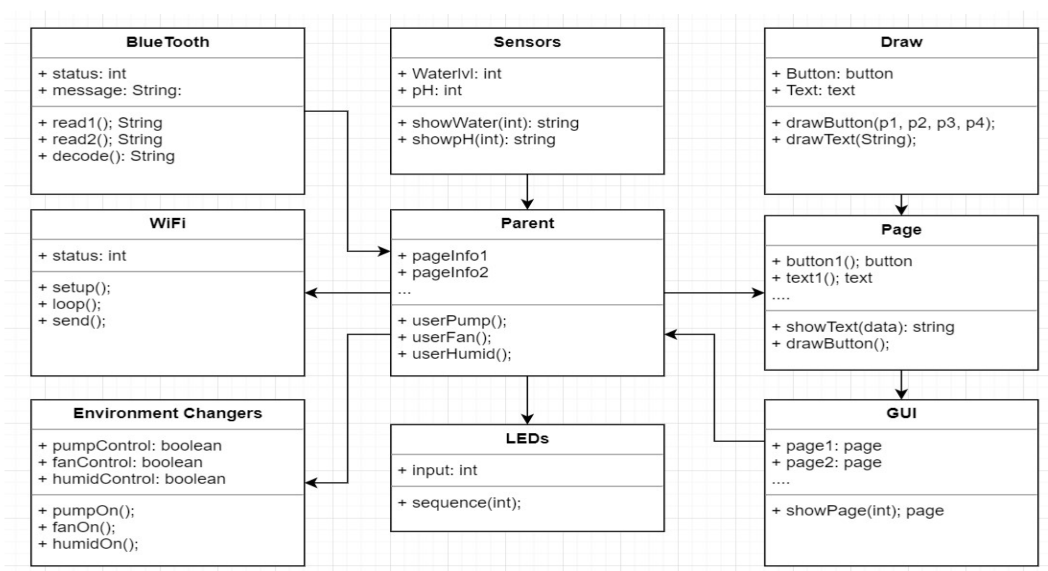

Figure 4 - Parent UML diagram

Embedded Design

The SmartLeaf device has 2 main components: a parent garden controller and child plant sensor nodes. The parent controller is based around the MSP432P401R chip by TI, which is a 32-bit Arm Cortex processor. The power of the MSP432 allows us to use multitasking to run several garden functions simultaneously. This controller is responsible for activating fans, water pumps, or the humidifier based on a timer or user web-control. The parent MSP432 also controls LED lighting for the system, monitors the water tank level with a water sensor, gathers plant data over Bluetooth, and publishes plant data over WiFi, and has a touchscreen LCD GUI.

To monitor the plants, we developed Bluetooth sensor modules that comprise of our various sensors such as temperature, humidity, and soil moisture controlled by a 16-bit MSP430g2553 MCU. Implementing a star architecture with Bluetooth requires each node to connect separately on different timing intervals. The sensor module's Bluetooth acts as the master, initiating the connection with the parent MCU's Bluetooth module open for connections. From the parent MCU, data from the sensors will be pushed to the cloud to be stored in our database and monitored on our Web-GUI. Each sensor node will consist of a lithium ion battery to keep it running wirelessly, the sensor equipment we use to monitor the plants, and FET headers for configuration and debugging. The Bluetooth module we chose is the HM-11 by JNHuaMao Technology. The module supports Bluetooth 4.0 using the TI CC2540 chip as its processor and is available in a sleek SMD footprint. The module is interfaced with using UART to recieve AT commands when not connected, and to send serial data when paired with another module.

The WiFi module used by our device's parent MCU is the CC3100 BoosterPack by TI. The module fits onto our PCB and offers a Network Processor along with an on-board chip antenna. The libraries offered by TI make interfacing with the module simple. There was no SMD version of this module, so we chose to stick with the BoosterPack instead of designing a whole RF module.

PCB Design

For the needs of the SmartLeaf system, three PCBs were designed: one for the child MCU, parent MCU, and one for the power rails/control circuitry. This solution saved more money than implementing a larger board and provided ease through the troubleshooting process. Eagle was utilized for its simplicity and its compatibility with the Webench Power Architect software used for the power design, as the regulator schematics and boards layouts could be directly imported into Eagle. The child PCB will be utilizing the MSP430G2553 microcontroller and communicating via Bluetooth with the MSP432P401R on the parent PCB. The latter will be directly connected to the voltage regulator PCB through a molex, which splits up the control lines for all major components in the project. The child PCB will be powered by a battery pack to limit the amount of wires running through the greenhouse. For the voltage regulator PCB, it was imperative to increase the width of certain traces to account for the high current demand of the LEDs. In order to impose uniformity in the design, all resistors and capacitors chosen were in 0805 packaging; this also made hand soldering these components more feasible were it to be required. The board layouts of the three PCBs used in the SmartLeaf system can be seen in Figures 5, 6, and 7 below.

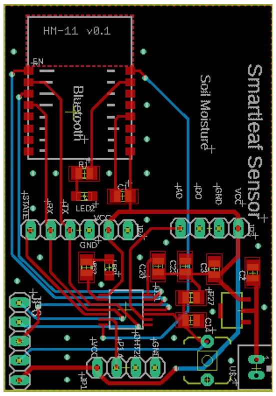

Figure 5: Child PCB

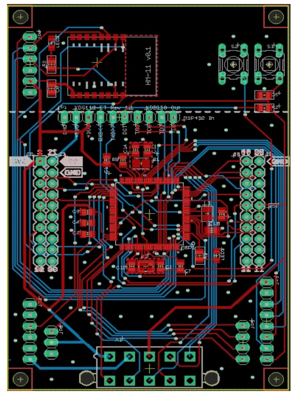
Figure 6: Parent PCB

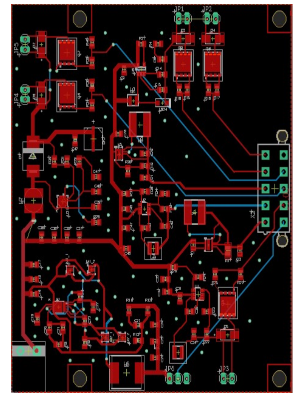
Figure 7: Voltage Regulator PCB

Budget & Financing

Though there were several unknowns at the start of the project, a budget of $500 was set. This proved to be a fairly accurate estimate, with the final number coming in at $441. Employing three small PCBs rather than one large board provided significant cost savings, as the price per surface area would have increased drastically if we were to size the board up. Additional savings came by way of recycling wood scraps from a nearby construction site (with permission, of course) and utilizing existing hardware for the physical build. The Plexiglas was a steep cost, largely due to us needing to have a hardware store cut the panels to size, as the first attempts to do it ourselves damaged the panels and left them with jagged edges. Table 4 shows a full breakdown of our budget.

Table 4 – Budget for the SmartLeaf System

Component	Price
Plexiglass panels	$100
Wood & miscellaneous hardware	$30
Water tanks, tubing, & sealant	$15
Pumps	$16
LEDs	$14
Power supply	$32
PCBs	$60
ICs & on-board components	$34
Humidity & temperature sensor	$9
Soil moisture sensor	$26
pH sensor	$30
Humidifier	$7
LCD	$30
Fans	$8
Plants & soil	$30
Total	$441

Conclusion

The SmartLeaf system was designed to help the everyday user get access to fresh produce regardless of location or environmental condition. Through the combined knowledge of electronics, embedded systems, and softwar development – gained both in previous classes and through this project – we were able to create a fun and innovative solution to indoor gardening.

References

[1] United States Department of Agriculture, "Food Access Research Atlas," USDA, Washington DC, 2019.